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FOUNDATION TREATMENTS USING SAND COMPACTION PILES AND SURCHARGE LOADING

MARINE CORPS AIR STATION IWAKUNI, JAPAN, A CASE STUDY

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ABSTRACT

Two, 42-meter diameter, 12.2 meter high (100,000 barrel) above ground jet fuel tanks are currently under construction by the Japan Engineering District (JED), U.S. Army Corps of Engineers for the Defense Logistic Agency (DLA) at Marine Corps Air Station (MCAS) Iwakuni. This presentation is a case study of the installation of Sand Compaction Piles (SCP's) and surcharge at MCAS Iwakuni. The geology below the tanks consists of poorly behaving liquefiable silty clays that can affect the bearing capacity of the loaded tanks. The site was formerly a marsh area filled with various debris and construction refuse and then covered with fill material. The elevation of the original marsh area is at sea level, and corresponds to the elevation of groundwater. The near surface soil consists of 6 to 12 meters of loose, liquefiable sand. Underlying this sand layer is 15 to 20 meters of soft, compressible clays and silts. A medium to dense sand and gravel underlies the soft clays and silts. The Iwakuni Faults, which are active faults, are located near MCAS Iwakuni. These faults are classified as Class B under the Japanese Standard, which is medium level in magnitude. The distance from MCAS Iwakuni to these faults is approximately 8 km. Foundation treatments to include SCP's, Sand Drainage Piles (SDPs) and surcharge mounds are used to improve foundation conditions. SCPs are not a deep foundation as in a typical pile, but rather a method for dynamically densifying loose sands. They have used extensively in Japan for many years to decrease the potential for liquefaction damage. Effectiveness of the SCPs in densifying the surrounding soils is determined by measuring the "N" value determined from a Standard Penetration Test taken in the area between the SCPs. The clay layer was consolidated using a soil surcharge. Percent consolidation was determined using vibrating wire piezometers.

INTRODUCTION

Two, 42-meter diameter, 12.2 m high (100,000 barrel) above-ground jet fuel tanks are currently under construction by the Japan Engineer District (JED), U.S. Army Corps of Engineers, for the Defense Logistics Agency (DLA) at Marine Corps Air Station (MCAS) Iwakuni. The tanks will be supported by the bearing capacity of the in-situ soils. These in-situ soils consist of saturated granular soils underlain by soft compressible silts and clays. To provide suitable foundation support for the tanks and to decrease the liquefaction potential of the saturated granular deposits beneath the tanks, foundation treatments to include a total of 4,767 Sand Compaction Piles (SCPs)/Sand Drainage Piles (SDPs) and surcharge mounds are being used to improve the foundation conditions. SCPs are not a deep foundation as in a typical pile. They are sand columns dynamically densified during placement there by densifying the loose adjacent sands. They have been used extensively in Japan for many years to decrease the potential for liquefaction damage. SDPs are sand piles that are placed the same way SCPs are except with less dynamic effort, their use is as vertical drains. On this project, the SCPs and SDPs shared the same hole, the SCPs extended through the granular materials to the top of the compressible silts and clays, the SDPs extended through the compressible material layer.

Surcharge mounds, 9.5 meters high, will be placed at both tank locations prior to the tank construction to reduce the compressibility of the fine-grained silts and clays. The SCPs/SDPs will be installed prior to the placement of the surcharge mounds. The SDPs will extend through the soft compressible silts and clays to shorten the time to consolidate these soils. The degree of consolidation of the clayey soil will be based on the pore pressures measured by piezometers placed in these soils at each tank location.

Enterprise Engineering Inc., Anchorage, AK, was the architect/engineer for design of this project. Saiki Research Studio, Tokyo, Japan, accomplished the geotechnical design under contract to Enterprise Engineering. The construction contract amount is $13.6 million and the prime contractor is Taisei Corporation, Tokyo, Japan.

SITE CONDITIONS

The MCAS Iwakuni is located in Yamaguchi Prefecture in southern Honshu Island, Japan, on a delta deposit formed at the mouth of the Nishiki River as it flows into the land-locked Sea of Japan. It is adjacent to the city of Iwakuni and approximately 50 kilometers west of Hiroshima and 300 kilometers west of Kobe, Japan. The MCAS area was originally part of the inland sea but was reclaimed over a period of many years. However, the land reclamation program was not completed and much of the MCAS remains low and marshy. The project site was formerly a marsh area filled with various debris and construction refuse and then covered with fill material. The elevation of the original marsh area was sea level. The addition of the refuse and fill raised the project site by approximately 2 meters.

GEOTECTONICS

The mountains surrounding the Iwakuni area consist of upheaval or intrusive granitic masses of the Cretaceous Period. Active faults known as the Iwakuni Faults are located near MCAS Iwakuni. These lineaments develop in the mountain zone and run along the borderline of the mountains and alluvial plane. These faults are classified as Class B (moderate to extensive structural damage) under the Japanese Standard, which is medium level in magnitude but high activity. The distance from MCAS Iwakuni to these faults is approximately 8 km.

SUBSURFACE CONDITIONS

A subsurface exploration program was undertaken at the site between January and March 2000. This program consisted of a total of 10 borings. The depths of the borings ranged from approximately 34 to 38 meters and disturbed and undisturbed samples were obtained. Soils investigations included standard penetration test (SPT) sampling and undisturbed 2-inch diameter fixed piston tube sampling of the cohesive soils. Except for the thin layer of fill on the surface, the subsurface conditions are indicative of materials deposited as part of a river delta. (See Fig. 1.) The uppermost layer, approximately 2 meters, consists of debris, refuse, and fill. A deposit of approximately 6 to 12 meters of loose, saturated sand underlies this material. Underlying the sand layer is approximately 15 to 20 meters of a compressible, soft silty clay deposit with interbedded pockets or lenses of sand extending to an elevation of approximately 26 meters below ground level. A loose to medium dense sand extending to an elevation of approximately 30 meters (below ground level) underlies the soft clays and silts. Beneath this sand layer is a layer of dense gravel. No borings encountered bedrock. Ground water was encountered at a depth varying from 1 to 2 meters below ground surface. The ground water elevation corresponds to mean sea level. An additional subsurface exploration program was done in March 2001. Four undisturbed samples were taken in the soft silty clays to reconfirm the settlement analyses.

LABORATORY TESTING

Testing of SPT samples consisted of visual classification of all materials, determination of Atterberg Limits, water contents, and gradation testing. Testing of the undisturbed samples included permeability, unconfined compression, and consolidation. Kajitani Engineering Company, LTD, Tokyo, Japan, performed the soil testing. Additional undisturbed samples were taken from two locations at the project site in March 2001. The U.S. Army Corps of Engineers, Engineer Research and Development Center (ERDC), Vicksburg, MS, performed consolidation testing on these samples.

FOUNDATION DESIGN

The foundation design consisted of the determination of the liquefaction potential and the bearing capacity of the upper saturated sand stratum and the foundation settlement due to consolidation of the silt and clay stratum. Bearing capacity was determined using the charts for footings on sand developed by Peck, Hansen, and Thornburn (1965). The 42 m diameter tank foundation consists of a concrete ring footing approximately 1.6 m in width. An allowable bearing capacity of 8.4 t/m^2 was obtained based on an overburden pressure of 3.9 t/m^2 and a depth to water table of 1.2 m. The total tank load is estimated to be 13 t/m^2. The existing upper sand stratum is incapable of supporting the tanks. The amount of settlement of the silt–clay stratum and the consolidation time was determined for both tanks. Maximum settlement will occur at the center of the tanks and was determined to be 79 cm. The maximum differential settlement obtained for the tanks was estimated to be 0.017 cm.

FOUNDATION RECOMMENDATIONS

Based on the above-mentioned foundation conditions and the type of structure to be constructed, a soil stabilization/soil improvement program was determined to be the most practical foundation solution. The soil stabilization selected was SCP. SCPs have been installed in the upper sand stratum beneath the footprint of both tanks and extending outward 10 meters from the tank side (See Fig. 2). The SCP design follows the standard industry practices developed in Japan. These design concepts were developed based on the contractor's substantial experiences involved with this type of foundation improvement.

SCP CONSTRUCTION

The tank construction was awarded to Taisei Corporation, Tokyo, Japan. Imori Kogyou Company, Japan, accomplished the construction of the SCPs. The SCPs were constructed using a vibratory hammer attached to the top of a 400 mm diameter steel pipe. The pipe casing is longer than the desired length of the sand compaction pile and fully supports the surrounding soil at all times during construction. The casing with attached vibratory hammer is suspended from a 35-ton crawler crane and is guided by leads. A coil spring shock absorber is fastened to the top of the vibrating hammer to dampen the shock as the casing is pulled from the ground by the crane. During driving, proper pipe alignment is maintained by a guide attached to the vibrator that moves up and down the leads on the crane. The steel casing is driven into the soil using the vibratory hammer. The steel casing is filled with sand as it is being driven down so that extraction of the casing can begin immediately upon reaching the required depth. Sand is loaded into the casing by filling the skip bucket attached to the leads. The skip bucket is lifted and dumped into a hopper located at the top of the pipe as it is being vibrated into the ground. Upon filling the casing with sand, approximately 70 psi of air pressure is applied to the top of the sand column. This air pressure applied to the top of the sand prevents soft soil from flowing into the pipe and helps force the sand out during withdrawal. (See Fig. 3.)

The SCP is constructed using a stroking (up and down) motion of the casing as it is withdrawn. The stroking motion is accomplished by pulling the casing up the hole 2 to 3 meters using the crane and then vibrating the casing back down 1 to 2 meters after the sand from the casing has been discharged into the hole. The effect of this stroking motion causes the sand discharged from the casing into the hole to densify and increase in lateral displacement (in diameter) which in turn, exerts an increased lateral pressure on the surrounding in-situ granular soils causing densification and decreased potential for liquefaction.

The SCPs were designed for a final diameter after placement of 700 mm. Adjusted

N-values greater than 20 were required for the densified granular soils between the SCPs after placement. This was verified in the field by check borings to determine the adjusted N-value of the in-situ densified soils. N-values were obtained prior to the placement of the SCPs. The initial N-values for the granular soils were less than 20. SPTs were done using a 2-inch diameter split spoon sampler. N-values and soil samples were obtained. The contractor sent the soil samples to a soils laboratory for gradation and hydrometer tests. These test results were used to correlate the N-values with the soil type in which it was obtained. As a result of the installation of the SCPs, the adjusted N-values for the granular soils were greater than 20.

SURCHARGE

Surcharge mounds consisting of compacted backfill material to a height of approximately 11 meters have been placed in the area of the tanks to consolidate the silt-clay layer. The consolidation of this layer is required to prevent excessive differential settlements from occurring that may damage the structure. Excessive differential settlements for these types of structures are considered to be less than 25 mm. Based on analyses done by the Geotechnical and Structures Laboratory (GSL), ERDC, it was estimated that differential settlements greater than 25 mm would not occur if the tank foundation reaches the 90% degree of consolidation prior to the removal of the surcharge. These analyses indicate a surcharge-loading equivalent to 125% of the tank load would keep the differential settlements to less than 25 mm and would also increase the post-earthquake strength of the silt-clay layer.

The time for 90% consolidation to occur at each tank was initially computed to be 260 days. To hasten this consolidation time, SDPs were placed through the silt-clay layer in conjunction with the SCPs. The materials and equipment to install the SCPs are the same as for the SDPs. The installation of an SDP reduces the length of the drainage path, thereby decreasing the time required to reach 90% consolidation. Installing SDPs on a square grid pattern at 3.0 meters center spacing with a 40 cm diameter for each SDP, the time required for the clay to consolidate to 90% of its primary consolidation is estimated to be approximately 45 days.

Percent of consolidation is being determined by pore pressure readings from the silt–clay layer. Four vibrating wire piezometers were placed at the approximate mid-depth of the silt-clay layer at the center of each tank. Readings are taken daily and the results are shown both in tabular form and graphically (See Fig. 4). Settlement readings of the surcharge mounds have also been taken. These readings indicate the foundation at Tank 17 has settled approximately 30 cm within the first week after placement of the surcharge mound. After 70 days from the date of final surcharge loading, Tank 17 had settled 60 cm as compared to the estimated 79 cm predicted settlement. At the writing of this paper, the percent consolidation had not yet been determined from a log plot, however, settlement and pore pressure readings were still being recorded.

CONCLUSIONS

Successful performance of the tank foundations required a detailed understanding of the site geology and an accurate characterization of the strength parameters and seismic conditions in order to design and accomplish the foundation modifications. The primary use of SCPs in Japan is to prevent foundation failures caused by earthquake shaking. When settlement is of a concern, preloading of the foundation is used after the SCPs have been constructed.

Of critical importance to this project was the check boring and instrumentation program to determine the effectiveness of the SCPs as well as the percent consolidation of the silt-clay layer. Induced pore pressures within the silt-clay layer beneath the proposed tanks locations have decreased over time after the completion of the surcharge mounds. This information will be used to inform the contractor as to when the surcharge mounds can be removed and actual tank construction can begin.

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